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Global statistics of microphysical properties of cloud-top ice crystals

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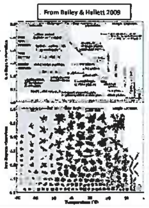
1: Motivation

Ice properties are important for radiation, cloud evolution, precipitation efficiencies, etc. Ice properties are known to vary with, e.g., temperature, humidity (see Fig. on left and below), and ice nuclei availability. Determining such relationships in the complex atmosphere remains elusive.



5: Definitions

Aspect ratio α is defined by the Length and Width of hexagonal prisms[4]:

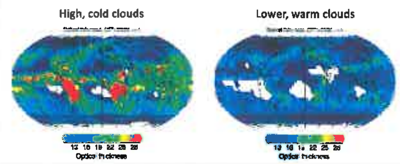
$$\alpha_{\mathrm{pl}} = \frac{\min(L,W)}{\max(L,W)},$$

Effective radius is defined by the total Volume (mass/solid ice density) and Area:

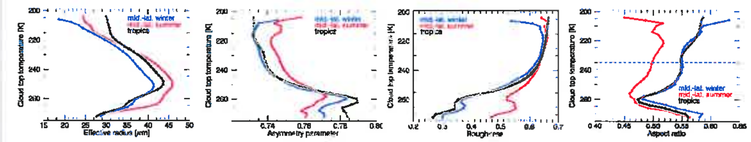
$$R_{\mathrm{eff}} = \frac{3}{4}\frac{V_{\mathrm{tot}}}{A_{\mathrm{tot}}},$$

Ice crystal roughness is a optical proxy for any microscale distortion of a smooth, solid ice crystal[7]. Other, similar parameterizations obtain similar results[6].

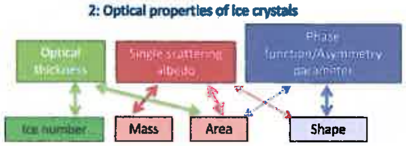
6: Global distribution of average optical thickness (of ice clouds with τ>1)



8: Seasonal variation of profiles (for ice clouds over ocean with τ>5)



2: Optical properties of ice crystals



Ice crystal shape characteristics mostly determining phase functions:

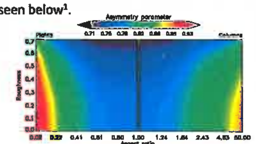
1. Aspect ratio of crystal components (meso-scale)
2. Surface roughness, distortion, impurities or cavities (micro-scale)
3. Habit (macro-scale)

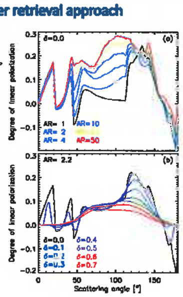
We focus on micro- and meso-scales since they are far more important than the macroscale (habits). Also 'Habit' is not quantifiable.
Simple hexagonal plates and columns are used as proxies for complex ice.

3: Shape and asymmetry parameter retrieval approach

Aspect ratios and roughness of proxy hexagonal prisms are retrieved by matching multi-angle polarized reflectance at 120°-150° scattering angles with a model. The relation between polarization and aspect ratio and roughness can be seen on the right[1].

The asymmetry parameter is uniquely determined by aspect ratio and roughness as seen below[1].

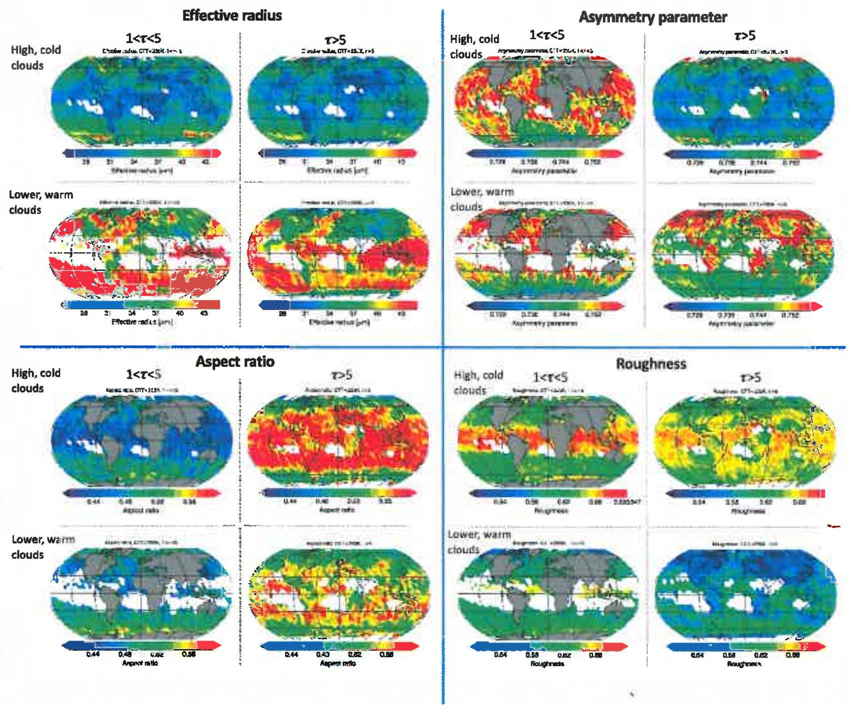




4: Data

- POLDER+MODIS collocated data at 6x6 km resolution for 2007
- MODIS collection 6 ice effective radius and optical thickness and height
- Conservative ice cloud filter: POLDER+MODIS phase index[5] + extra rainbow detection phase index[2]

7: Yearly-averaged global distribution of cloud-top properties



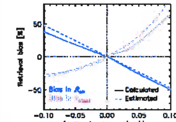
9: General tendencies

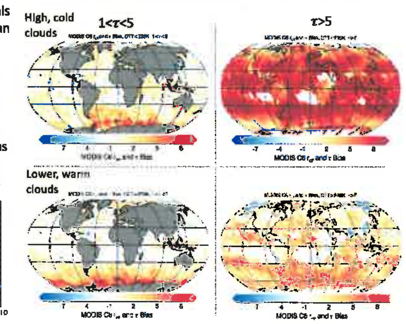
	Cloud top temperature	Optical depth	Latitude	Land vs ocean	Summer vs Winter
τ	↓	--	↓	↑	↑ ↓
Effective radius	↑	↔	↑	↓	↑
Asymmetry parameter	↑	↓	↑	↑	↑
Aspect ratio	↓	↑	↑ ↓	↔	↓
Roughness	↓	↔	↓	↓	↑

10: Implied % bias on MODIS C6 retrieved r_{eff} and τ from constant asymmetry parameter

MODIS collection 6 retrievals assume an ice model with an asymmetry parameter of 0.754 in the visible.

When the real asymmetry parameter is g, this assumption creates biases of $(1-g)/(1-0.754) \times 100\%$, as seen below[3]. Maps on the rights show average biases.





11: Notes

- Most of the crystals are identified as plate-like
- Roughness is often found to be its maximum value of 0.7
- Results are filtered for acceptable RMS value for fit
- Ocean surface is assumed for low optical depths

References

van Diedenhoven et al 1: AMT 2012; 2: JAS 2012; 3: JGR 2014; 4: JAS 2016

5. Riedi et al. ACP 2010;
6. Geogdzhayev & van Diedenhoven JQSRT 2016;
7: Macke et al. JAS 1996